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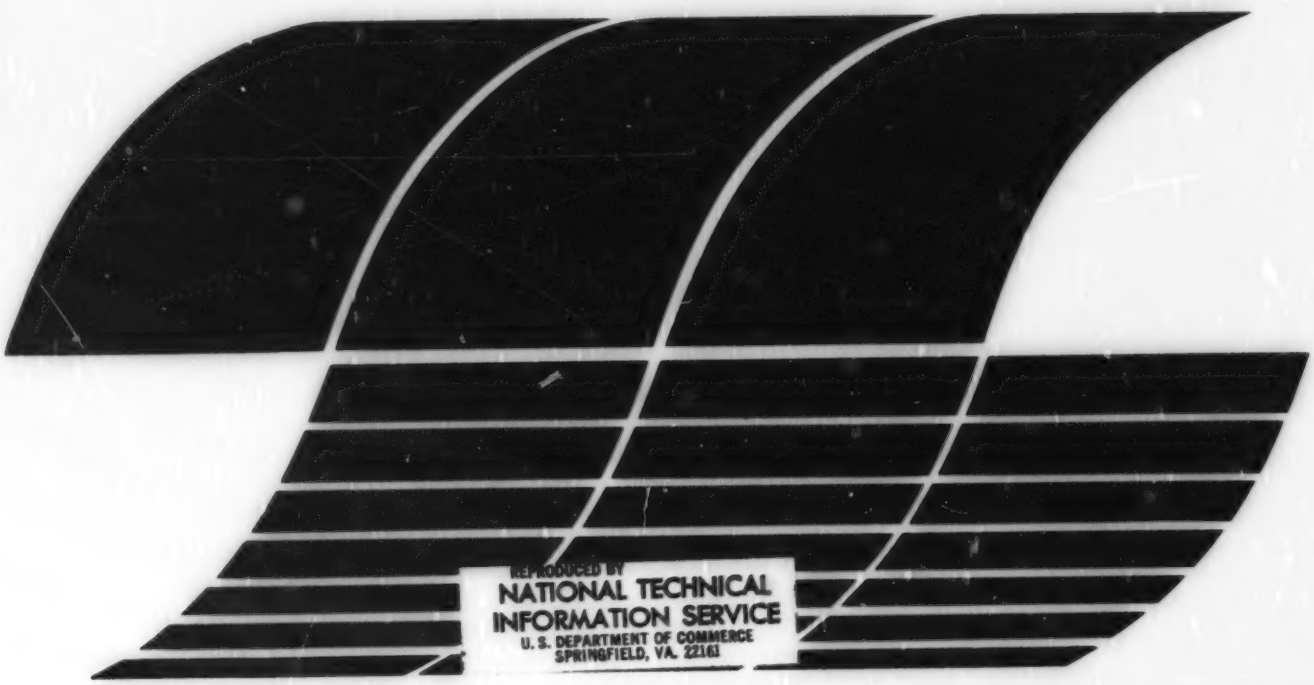
Advanced Fossil Fuels and the Environment



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16. Abstracts

This executive-level report gives an overview of some of the more advanced fossil fuel technologies, including several Chemical Coal Cleaning and Liquid Fuels Cleaning methods. Synthetic fuels, Chemically Active Fluid Beds, and Oil Shale are also considered as viable advanced processes and control technologies. The overview includes a discussion of these processes, state-of-the-art, and environmental impacts which are being, or have been, investigated.

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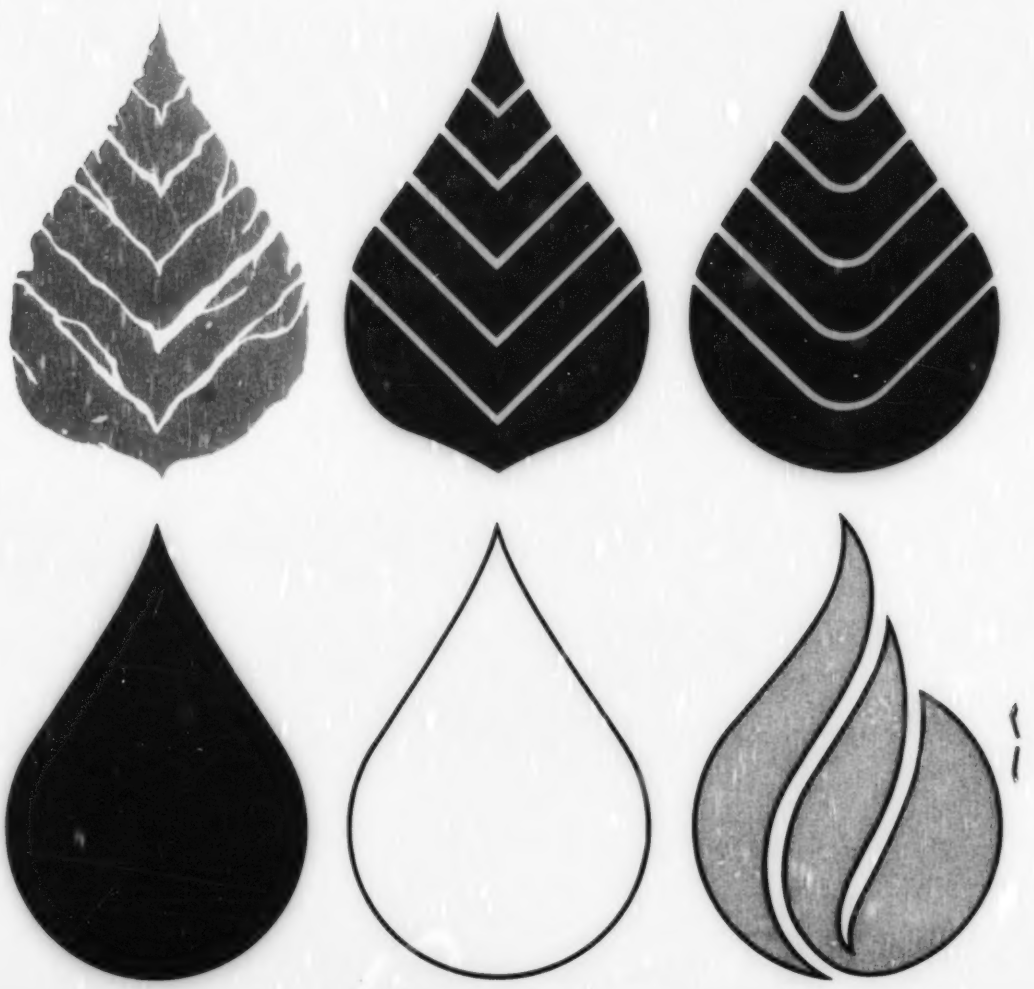

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INTRODUCTION

Purpose

This report reviews the environmental control technologies being developed in concert with advanced fossil fuel conversion processes. These control technologies are designed to eliminate the adverse health and ecological effects that are often by-products of energy conversion.

While specific fuel conversion processes are examined in this report, it should be emphasized that EPA's major interest lies with the type and quantity of pollutants from the processes and the practicality and effectiveness of pollutant control methods.

With its involvement in the actual conversion process, however, EPA is striving to assure that the new and evolving conversion processes will develop environmentally sound as well as efficient. Additionally, as the report reflects, EPA is working to prevent pollution from conversion processes already developed and in use. EPA also performs environmental assessment of control technologies; however, this report does not deal directly with this agency function.

Program Sponsor

The Federal Interagency Energy/Environment Research and Development Program is a seventeen-agency effort committed to energy development with environmental protection. Major program goals are to:

> Safeguard health and the environment without unduly delaying the accelerated development and use of domestic energy resources.
>
> Anticipate environmental impacts of energy conversion technologies and develop cost-effective environmental controls.
>
> Promote the transfer of energy-related environmental information.

The Office of Energy, Minerals and Industry (OEMI), within EPA's Office of Research and Development, plans and coordinates this Interagency Program. Through this Program, OEMI provides support to numerous other federal agencies including the Energy Research and Development Administration (ERDA) and the National Institute for Occupational Safety and Health (NIOSH).

FY77 Interagency Program funding was $97 million, of which $26 million was passed on by EPA to other federal agencies. This funding supports a number of ongoing, energy-related programs. These include characterization and monitoring of pollutants, transport processes, ecological effects, health effects, integrated technology assessment studies, and environmental control technology. This information allows EPA to decide where its control technology development funds can be most effectively invested.

The Program seeks to develop control technologies that can be integrated into energy production processes as they are brought to commercial use. Successful development of environmental controls in tandem with development of energy production processes will avoid the more costly and less efficient task of disposing of pollutant wastes after they have reached the environment.

Advanced Fossil Fuel Environmental Control Technology

Control technology development is directed toward removing pollutants from both the discharge stream of an energy conversion process as well as the process stream itself. Even following development, however, application of these controls is open to question.

Will the controls, in fact, reduce pollutants to levels that pose no threat to health or ecology? Are they effective *enough*? What are the realistic costs of these controls, both in dollars and in lost energy? How serious is the trade-off between lost energy and found environment? And, does this trade-off have to exist at all? These are serious questions, with answers being sought through the research carried out under the Interagency Program.

There is no question, however, that energy conversion processes produce pollutants as by-products. Many of these are severe health hazards — some have impacts that may take years to become manifest in clear-cut damage to health or the environment. Emissions standards must, therefore, be established and enforced to protect human health and key environmental relationships before these pollutants get out of hand.

Deriving these standards for the present requires constant and careful evaluation of existing technologies. Deriving them for the future requires timely development of environmental control technologies for emerging fossil fuel processes, allowing for the identification, measurement, and mitigation of these pollutants and their sources before there is widespread dispersion of both the pollutants and the energy technologies that produce them.

With the concurrent development of the processes and the environmental control technologies, a balance is

achieved. As one becomes more sophisticated, the other naturally follows — evolving environmental controls to accommodate evolving process technology.

More ideally, with the potential evolution of conversion processes with 'built-in' environmental controls, an energy conversion technology may evolve that is at once feasible and economical, as well as environmentally sound. In the long run, working toward this end may well be the most cost-effective solution.

Now, in the final quarter of the twentieth century, the focus *is* indeed shifting to the development of such new total processes — ones that are inherently cleaner than current methods and that depart from the former practice of worrying about the mess after it has been made. Advanced fossil fuel environmental control technology is a key tool necessary to bring about these total process fuel conversions.

Processes/Control Technology

The five major advanced fossil fuel processes and control technologies examined in this report are:

Chemical Coal Cleaning — four major processes. Methods of removing organic and pyritic sulfur and other contaminants.
Synthetic Fuels — gasification and liquefaction to provide synthetic fuels from coal. Reduction of gaseous, liquid, and solid waste during and after conversion.
Chemically Active Fluid Bed (CAFB) — producing clean gas from sulfur-laden heavy residual oils.
Oil Shale — control of processing effects on the environment during recovery of oil from kerogenous shale.
Liquid Fuels Cleaning — methods of removing contaminants from liquid fuels before combustion.

The report's major concern is with those technologies that can be applied before or during fuel combustion or resource conversion. Environmental controls for post-combustion processes such as flue gas desulfurization are not treated here, although there is considerable money and technical effort being expended in this direction.

While environmental control technologies are discussed separately in the report, it may be that ultimately their most effective use is through the combination of two or more in a process stream.

Advanced Fossil Fuel Ramifications

Efficiency — Many cost/supply relationships must be firmly established before the efficiency of a given process can be determined. It is assumed, for instance, that advanced processing used to produce fuel from high-sulfur coal and oil shale will consume more energy than current conversion methods. We may, therefore, be trading traditional conversion efficiency for adequacy of national energy supply. However, the total energy expended — conversion plus cleaning — may be less at certain stages in an overall process stream than is now the case in conventional conversion methods. Clearly, it will be important to establish an accurate basis for determining efficiency.

Use — Advanced fossil fuels will be used to greater or lesser extent by different sectors of the economy. In the near term, for example, smaller users of conventional combustion who, for reasons of cost or location, cannot adopt gasification or liquefaction techniques can be expected to benefit from chemical coal cleaning technology. Large industrial users of gas and oil are expected to turn to advanced fossil fuels by the turn of the century when traditional fuel sources are predicted to be critically scarce and prohibitively expensive.

Environment — The various environmental effects of advanced fuel processes will be felt most significantly on the local or regional level — those areas where advanced processing plants and fuel sources are to be located.

The different technologies associated with these processing plants and fuel sources will produce different types and amounts of pollution. Among the most hazardous pollutants will be sulfur in its various forms, nitrogen oxides, chemical compounds such as phenols, aldehydes, and ammonia, particulates, toxic trace metals, tars, oils, and dust. There also may be new pollutants whose hazards are not yet known.

Control technology research will allow the anticipation and moderation of most of these potential environmental pollutants. It must be said, however, that not until the actual fuel conversion plants are operational will the full character and magnitude of the by-products of advanced fossil fuel processes be understood.

Advanced Fossil Fuel and Industry

To date, some industries are evolving conversion process technology with their own funds. Most, however, say they must have federal subsidies to adequately finance advanced fossil fuel programs.

Industry, however, has shown only a limited interest in pollution control technologies for advanced fossil fuels. It is apparent therefore that, until government-supported programs prove the economic and technical feasibility of the large-scale processing of advanced fossil fuels, industry will reserve judgment, as well as major man-power and financial commitment.

Future Course

A major effort is underway to make America less dependent on foreign sources of energy. The possibility is real, but its realization does not lie in the near future. In the years to come, the nation must conserve the energy it has, harness new sources, and work to develop the energy sources already identified, including its vast coal reserves and oil shale deposits. Efficient, economical ways of extracting energy from these sources must be developed while at the same time giving full credence to the basic imperative:

> *That energy resource development cannot come at the expense of the quality of our health or of the natural environment.*

CHEMICAL COAL CLEANING

Process

Chemical coal cleaning is used to remove sulfur and other pollutants from coal before it is burned. Sulfur is found in coal in two general forms: organic and pyritic. Organic sulfur is part of the molecular structure of coal, while pyritic sulfur, or iron sulfide, is part of the mineral portion of coal. The sulfur content of coal, both organic and pyritic, ranges from less than 1% to over 8%, depending on the coal type. Pyritic sulfur accounts for about half of the total sulfur in a given type of coal. When coal is burned, the pyritic sulfur, along with some of the organic sulfur, is transformed to sulfur dioxide and becomes a major source of air pollution. Chemical cleaning, which involves leaching to wash out pyritic sulfur and heating to break the bonds that bind the organic sulfur to coal, is potentially more effective in ridding coal of its pollutants than conventional physical cleaning methods.

Four chemical coal cleaning methods are currently being evaluated by EPA. These are:

- Meyers process
- Hydrothermal process
- Flash desulfurization process
- Microwave process.

Meyers Process — In the Meyers process, a heated liquid iron sulfate leaching solution is reacted with ground coal. This leaching action releases pyritic sulfur as well as iron, alkaline ash, and other impurities. Following the leaching, the coal is washed to remove these contaminants and the leaching solution is then processed for reuse. No organically bound sulfur is removed because the leaching solution does not penetrate the carbon-coal matrix. The Meyers process is 95% effective in removing pyritic sulfur in pilot plant tests (7 metric tons per day).

Hydrothermal Process — The hydrothermal process adds a leaching solution of sodium hydroxide, calcium hydroxide, or their combination, to a mixture of crushed coal and water at moderate temperatures. This heating/leaching transforms the solid sulfur compounds and ash to a solution, which can then be separated from the coal. This process removes up to 95% of the pyritic sulfur and 40% of the organic sulfur in pilot plant tests (¼ ton per day).

Flash Desulfurization Process — This process exposes coal to hydrogen at low pressure and high temperature. In this reaction, the sulfur in the coal is released into the gas stream where it is purified. Flash desulfurization removes over 90% of the total sulfur content of coal in laboratory tests.

Microwave Process — The microwave process heats coal to high temperatures so that the volatile parts of the pyritic sulfur are vaporized for separate recovery. This process is being evaluated to determine how much of the sulfur can be removed.

Rationale

The successful development of chemical coal cleaning and its adoption by the public and private sectors could potentially:

Assure removal of pyritic and organic sulfur from coal, while at the same time maintain a high level of energy content in the cleaned coal. Physical coal cleaning methods in industrial use today remove some of the pyritic sulfur but do not remove organic sulfur. The amount of pyritic sulfur removed by physical methods ranges from 50% to 70%. In removing this pyritic sulfur, however, physical cleaning methods also significantly reduce the energy content of coal.

Offer a viable alternative to smaller users of coal for control of air pollution from combustion. Some industrial users of coal may not be able to use flue gas desulfurization equipment because its size may be incompatible with installed combustion equipment, or the cost of adding stack gas scrubbers may preclude economical operation of the industrial plant.

Provide an economic advantage to coal users. Initial cost/benefit analyses of cleaning coal using both chemical and physical methods plus flue gas desulfurization indicate a net cost saving to coal users compared with the use of flue gas scrubbers alone. Although some of the coal is inevitably lost in the cleaning process, thereby reducing the total

heating value available, the cleaned product is more efficient in the production of energy (that is, higher heat values are obtained for a given amount of coal burned). Initial estimates suggest that this efficiency could help to offset the cost of cleaning. Offsetting factors include reduced coal transportation costs, less residue produced in burning the cleaned coal, which lowers the cost of boiler maintenance and waste disposal, and the lowered cost of stack scrubbers, which need not be as large or elaborate since the ash content of cleaned coal is at a minimum.

Increase the amount of usable U.S. coal resources for conversion to energy. Eastern coal reserves, for example, previously unusable because of high-sulfur content, could be tapped. In fact, 90 billion tons of Appalachian coal could be processed without costly post-combustion desulfurization while still meeting standards. The ability to meet new source performance standards is, of course, a prime objective of industrial and commercial users of coal. It is an important objective as well of EPA to alert potential users to developments that can help them meet these standards.

FLASH DESULFURIZATION

Factors

Technological — Chemical cleaning is feasible for a variety of coal types, although the energy remaining in the coal after cleaning varies with the specific cleaning process. Some coal is inevitably lost in the effluent discharge of the cleaning process, which reduces the amount of energy left. Moisture added to the coal during cleaning also reduces the energy value of the coal. This energy loss penalty due to moisture is most severe for the fine particle coals used thus far in testing chemical cleaning methods. Consequently, part of the task of proving the viability of chemical cleaning of coal is to find ways of recovering the coal lost in the effluent and of dewatering the coal after it is cleaned.

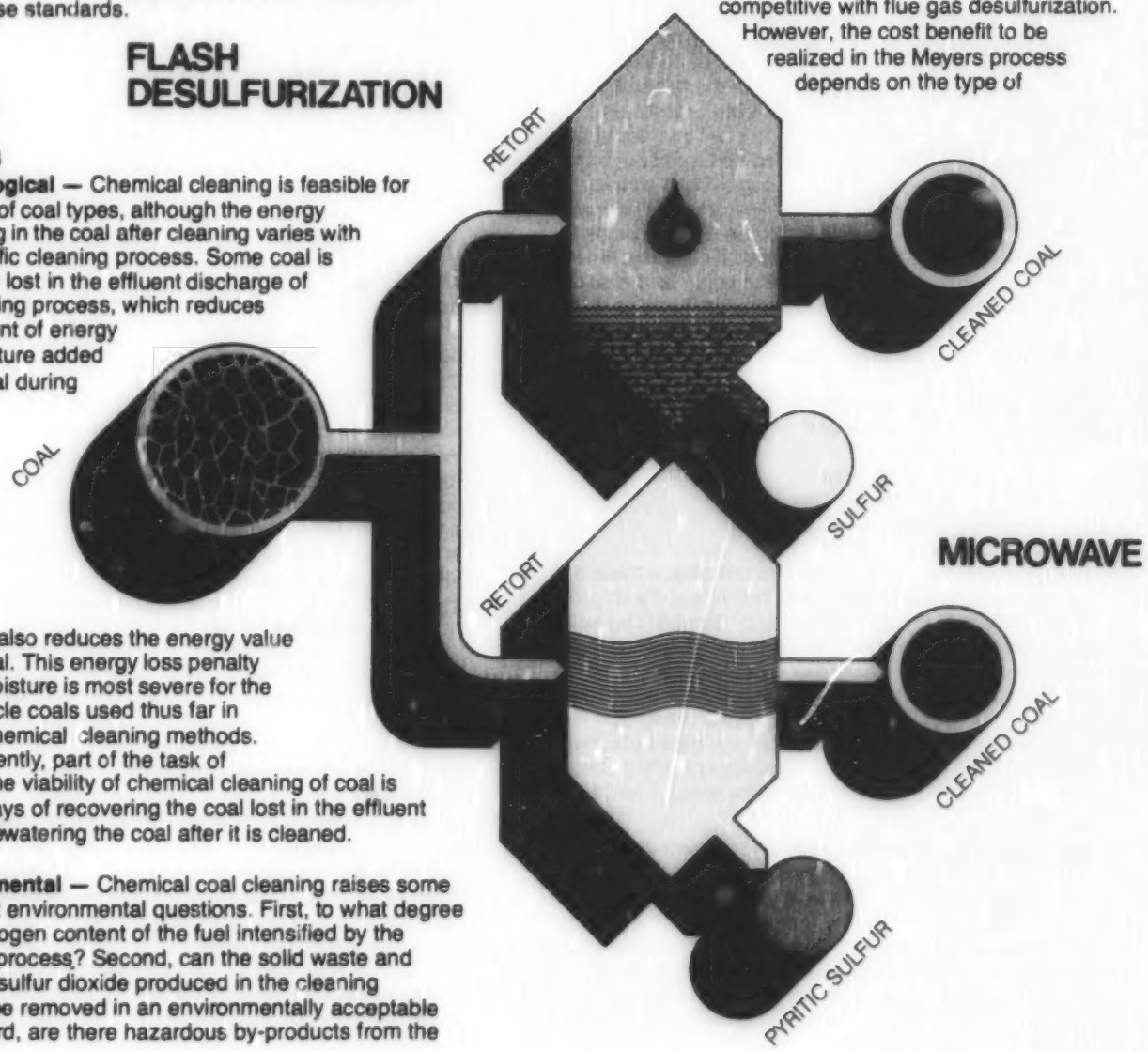
Environmental — Chemical coal cleaning raises some important environmental questions. First, to what degree is the nitrogen content of the fuel intensified by the cleaning process? Second, can the solid waste and gaseous sulfur dioxide produced in the cleaning process be removed in an environmentally acceptable way? Third, are there hazardous by-products from the cleaning process that may be present but unidentified? And fourth, will the ash from cleaned coal have an adverse effect on the efficiency of electrostatic precipitators?

Environmental concerns related to coal cleaning — chemical as well as physical — include reclamation of harmful trace elements that may be concentrated in the cleaning waste, and the control of dust in the immediate area of coal handlers to lessen potential respiratory hazards.

Economic — There are major cost uncertainties in the four processes under evaluation.

Primary cost elements in the Meyers process are in leaching, regeneration of the leachate, and in coal dewatering and drying. The process could potentially be less expensive than the hydrothermal, flash desulfurization, and microwave heating techniques, but the comparative costs of the four processes are not yet firmly established.

The Meyers process may become cost competitive with flue gas desulfurization. However, the cost benefit to be realized in the Meyers process depends on the type of



coal cleaned and its pyritic sulfur content. If the Meyers process proves to be efficient and economical, this could be an advantage to small industrial users of coal who may not be able to afford stack-gas contaminant removal technologies.

Program

The four chemical cleaning methods being sponsored by the EPA Interagency Program are currently undergoing careful evaluation:

Meyers Process — Development is at the pilot-plant stage and is receiving the major portion of current Interagency Program funds allocated to chemical coal cleaning because it appears to be the most promising of the four technologies under study. EPA is funding $4 million for a one-year demonstration of the process, scheduled to begin in the spring of 1977. The reactor test unit was designed by Procon, Inc., Los Angeles. Construction of the unit began in November 1976, at a site near Capistrano, California. TRW, Inc., Redondo Beach, California, will operate the pilot plant. The unit, which will treat about 7 metric tons of coal per day, performs only leaching and regeneration operations. Dewatering, drying, and sulfur removal will be done in the laboratory using coal samples from the test unit. Bench-scale support and applicability studies will be carried out concurrent with the test of the pilot plant.

The actual operation of this pilot plant is expected to demonstrate more effective coal cleaning processing and lower costs than previously indicated in laboratory and bench-scale tests. If these expectations are realized, EPA may recommend completion of the pilot plant to add dewatering, drying, and sulfur removal equipment. Further testing will then define process applicability, design, and cost data. Industrial and utility support will be sought during the test to help identify practical operating problems.

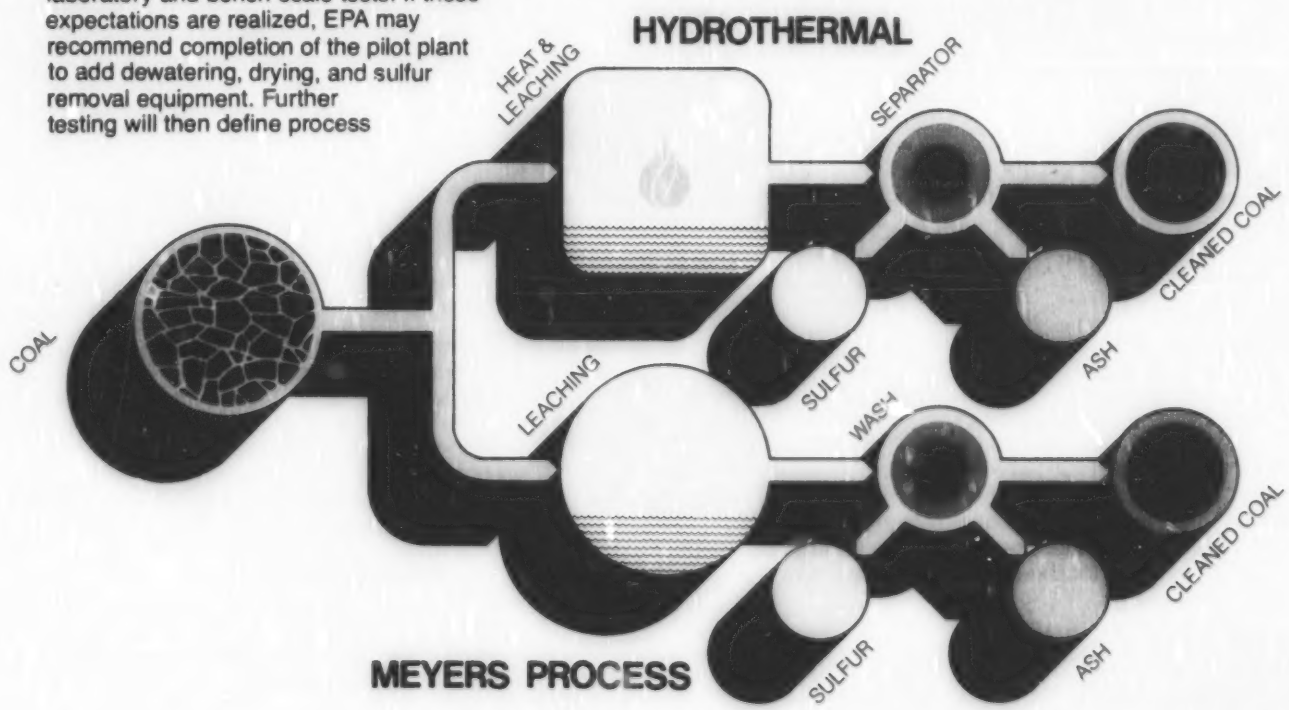
Flash desulfurization — Experiments are under way at the Institute of Gas Technology (IGT) in Chicago to establish the potential of this process. EPA is funding $370,000 for this 20-month project. Chemical reactions to remove nitrogen as well as sulfur are being evaluated as a part of this EPA-sponsored program.

Hydrothermal coal cleaning — This process was investigated by Battelle Laboratories in Columbus, Ohio. Although the process is technologically feasible, it does not appear to be cost competitive with other chemical coal cleaning methods.

Microwave treatment — Research performed at General Electric Company, Valley Forge, Pennsylvania, is currently being reviewed by EPA to determine the potential of microwave treatment to release both the pyritic and the organic sulfur in coal.

EPA also has a large ongoing program of environmental assessment of chemical coal cleaning processes. Process streams, compounds, and discharges that have adverse health and ecological effects are being analyzed. Results are used to establish permissible concentrations of potentially hazardous substances. Environmental guidelines for developers of coal cleaning processes will be based on the permissible concentrations determined in these studies.

As an adjunct to this chemical cleaning research, EPA and the U.S. Bureau of Mines plan to use computer modeling



to investigate the economy and efficiency of various combinations of physical and chemical coal cleaning methods. A preliminary economic analysis conducted by the Bureau of Mines under the Interagency Program indicates that, in many cases, physical coal cleaning — alone or in combination with partial flue gas desulfurization — is cost competitive with flue gas desulfurization by itself.

Agency Interaction

As a part of the Interagency Program, EPA is fostering research in chemical coal cleaning both directly and through other agencies. Research projects are also being funded in cooperation with industry.

Directly funded research contracts by OEMI are those with TRW, Inc., for the Meyers process pilot plant, and with IGT for flash desulfurization studies.

Until recently, Kennecott Copper Company's Ledgemont Laboratories were actively investigating oxygen leaching of coal to convert pyritic sulfur to sulfates for ready disposal. This work was suspended by Kennecott after the Federal Trade Commission ordered the copper company to divest itself of Peabody Coal Company.

OEMI is providing Interagency Program funds to the U.S. Bureau of Mines Coal Preparation and Analysis Group for physical and chemical coal cleaning technology development including construction of a coal washing facility in Pittsburgh, Pennsylvania. The Bureau of Mines group is also studying the cleanability of coal and methods to minimize coal cleaning waste by-products. ERDA's Environment and Safety Group at Los Alamos Scientific Laboratory, OSHA/NIOSH, and the U.S. Geological Survey are conducting evaluations of the effects of chemical coal cleaning on the environment, also under the Interagency Program.

Outlook

Chemical coal cleaning is an antipollution technique that removes contaminants very early in the process stream, before combustion. By removing contaminants before combustion, chemical coal cleaning offers not only a potential environmental benefit but it may cost less than retrofitting post-combustion pollution control techniques.

Basic technological and economic questions remain to be answered, however, before the viability of chemical coal cleaning is assured. Will utilities and developers of synthetic fuels processes consider using the technology? Will it be possible to bring the technology to small industrial users, users who can ill-afford their own research and development and have little contact with EPA programs? Chemical cleaning may, in many situations, offer them the most economical way of meeting environmental regulations.

These questions are by no means moot. At present, there is little incentive among coal producers and users to invest in the development of chemical coal cleaning techniques because of the uncertain economics of the processes. Consequently, responsibility for proof of the technology will fall mainly on government-sponsored efforts.

Chemical Coal Cleaning Facts

Process: Leaching or heating of coal prior to combustion to remove portions of ash, pyritic sulfur, and sometimes organic sulfur chemically bound to the coal.

Purpose: Make high sulfur coals available for use.
Permit emission standards to be met.
Decrease scrubber costs and by-products.
Permit coal cleaning plant to be located near the mine, thus keeping waste away from power plants.

Problems: Possible scaling and corrosion of industrial boilers.
Disposal of solid waste from cleaning operations.
Nitrogen intensification in cleaned coal.
Hazardous by-products of cleaning.
Installation and operating costs.
Costs to users.

Potential: May offer economically superior alternative to pollution control retrofit. Processing costs may be offset by environmental benefits. May allow small users who cannot afford other controls to meet emission standards.

SYNTHETIC FUELS

Process

The federal government is giving priority to the development of coal gasification and liquefaction processes. Such processes, it is hoped, will produce an adequate supply of synthetic gaseous and liquid fuels as sources of domestic petroleum are exhausted and petroleum imports become more expensive. The prime responsibility for the actual development of these coal conversion processes belongs to ERDA. The EPA responsibility is to ensure that these processes do not create adverse health and ecological effects. Major EPA concerns are the nature of pollutant by-products, the locations in the process stream where environmental control technologies should be integrated, and the development of effective environmental control techniques.

Synthetic fuel development research is concentrated on producing substitute natural gas (SNG) and liquid fuels, primarily for use as refinery feedstock and in electric power generation. However, gasification units are already being used by industry and more are scheduled to be installed. Thus, it is logical to assume that industry, rather than the electric utilities, will be the first to adopt advanced gasification techniques as they become ready for commercial use.

Coal gasification can produce low-, medium-, and high-Btu gas. The low-Btu gas has a heating value of 100 to 200 Btu per cubic foot and is used as a fuel feedstock or to generate power in combined gas-steam turbine power cycles. The medium-Btu gas has a heating value of 300 to 650 Btu per cubic foot and is usually used as a feedstock in the production of high-Btu gas. This high-Btu gas, with a heating value of 950 to 1,000 Btu per cubic foot, can be substituted for natural gas in industrial and residential consumption.

Coal liquefaction is used to produce an entire range of liquid products from coal. These products include fuel oil, gasoline, jet fuel, and diesel oil. Processes are being developed and improved to increase the supply of nonpolluting liquid fuels as well as to facilitate their transport and use. Current emphasis is being placed on the development of lower grade synthetic fuels suitable for firing industrial and electric utility boilers and gas turbines.

Coal Gasification Process

Coal is gasified by applying heat and pressure or a catalyst to break down the components of coal to form a synthesis gas containing mainly carbon monoxide, hydrogen, and some methane. The gas formed in this way may also contain carbon dioxide, nitrogen, water vapor, and contaminants such as hydrogen sulfide and ash.

In simple gasification, a synthetic gas is produced by reacting coal with steam or hydrogen and air or oxygen. If air is used, a low-Btu, nitrogen-rich gas is produced. The nitrogen limits the heating value of the synthesis gas and could cause release of environmentally hazardous nitrogen oxides (NO_x) if the gas were burned as fuel. The gas also will contain sulfur oxides and other pollutants that have to be removed.

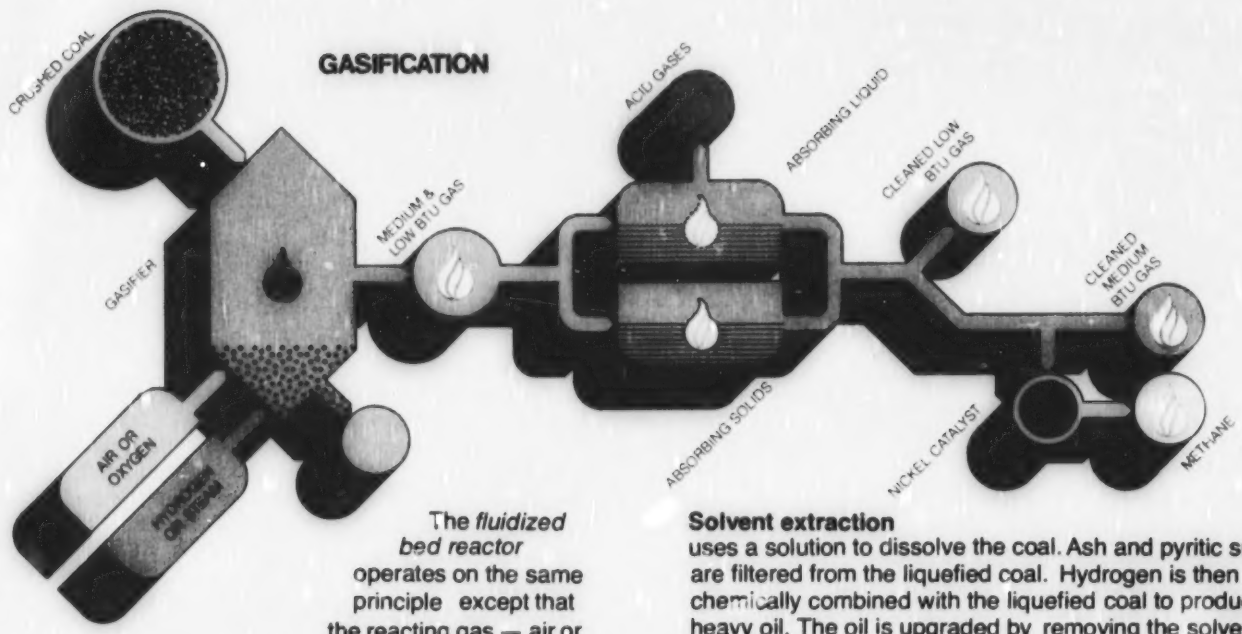
Alternatively, if oxygen is used, medium-Btu gas is produced. This product gas contains some sulfur oxides but no nitrogen. It is usually intermediate to the production of high-Btu gas.

Other gasification reactions use hydrogen instead of steam. This produces more methane directly in the synthesis gas than is produced in simple gasification. Consequently, the medium-Btu gas produced by hydrogasification requires less additional processing to be transformed to a high-Btu gas. Moreover, higher overall conversion efficiencies can be realized with hydrogasification than with simple gasification.

High-Btu gas is made from low- and medium-Btu gases by adjusting the ratio of hydrogen to carbon monoxide in these gases. This ratio adjustment is called the water-gas shift reaction. The gas is also purified by removing the acid gases produced in the reaction, chiefly hydrogen sulfide and carbon dioxide. The remaining hydrogen and carbon monoxide are then combined to form methane and water — a methanation reaction. The water is then removed leaving a methane-rich product with the essential characteristics of natural high-Btu gas.

Gasification is carried out in either a fixed bed reactor, fluidized bed reactor, or entrained bed reactor.

In the *fixed bed reactor* crushed coal is fed to the reactor to form a bed. Air or oxygen and steam are blown upward through the bed at a relatively low velocity to gasify the coal. The raw synthetic gas exits from the top of the reactor and is quenched to remove tars, oils, and particulates. The gas is then cooled for further processing.



The *fluidized bed reactor* operates on the same principle except that the reacting gas — air or oxygen and steam — piped through the reactor "fluidizes" the coal, producing a "boiling" effect as the coal is gasified. The advantage of fluidization is that it forces the coal particles apart, exposing more of their surface to the reacting gas, which increases the gasification efficiency.

Finer coal particles and a reacting gas of high velocity are used in the *entrained bed reactor.* During gasification, the coal particles are swept along in the vertical flow of the reacting gas. The coal particles are filtered from the gas, which is then recycled through the reactor until a product gas of suitable heating value is obtained.

Currently, all three types of reactors are on the commercial market and are operating at various gasification plants throughout the world.

Coal Liquefaction Process

Coal liquefaction has the same chemical basis as coal gasification. Only the ratio of carbon to hydrogen in the end product is different.

Coal can be liquefied by four basic methods:
- Direct catalytic hydrogenation
- Solvent extraction
- Pyrolysis
- Liquid hydrocarbon synthesis.

Direct catalytic hydrogenation mixes coal with oil and hydrogen and passes it through a reactor at high temperature and pressure. The coal reacts with the hydrogen to produce additional oil that is then separated from the remaining contaminant solids. During World War II, Germany had a direct catalytic hydrogenation plant that produced gasoline at a maximum of 64,200 barrels per day.

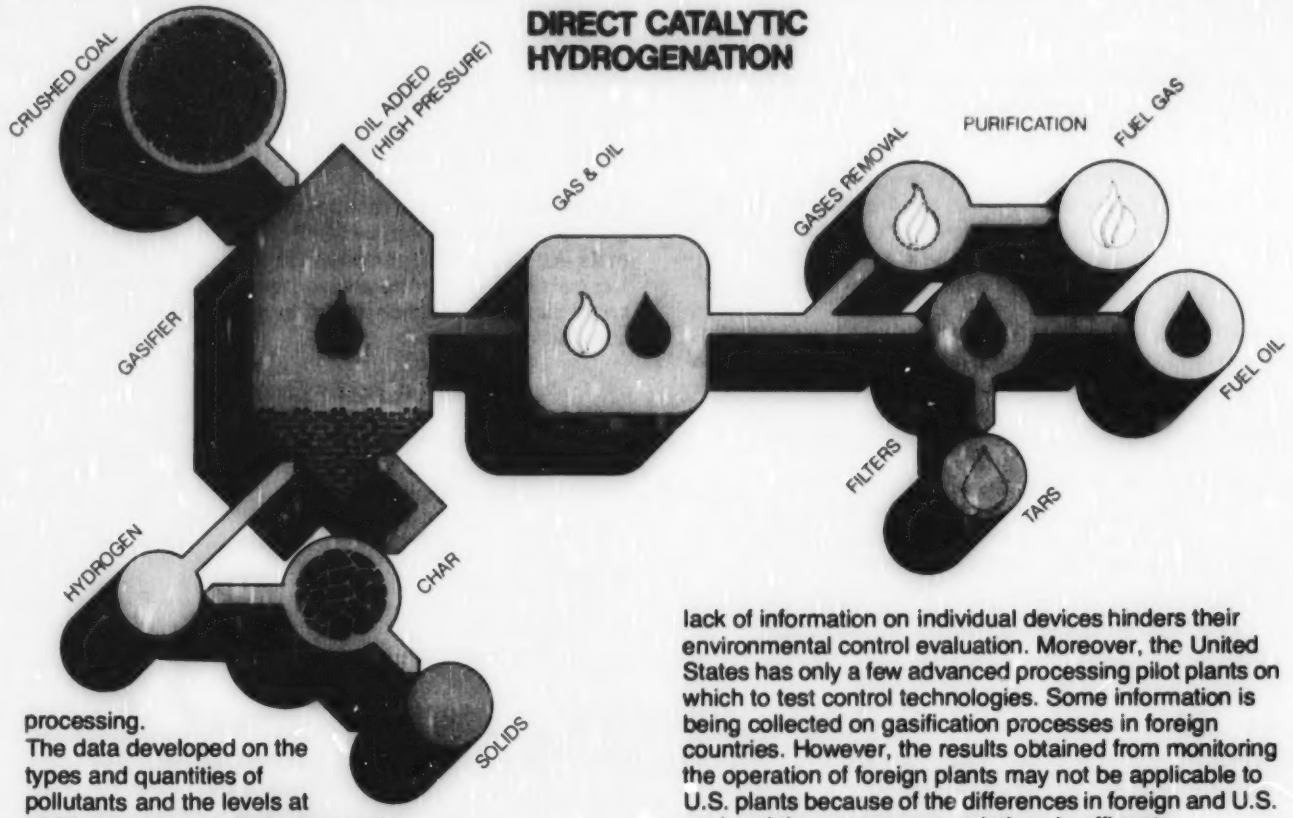
Solvent extraction uses a solution to dissolve the coal. Ash and pyritic sulfur are filtered from the liquefied coal. Hydrogen is then chemically combined with the liquefied coal to produce a heavy oil. The oil is upgraded by removing the solvent and adding more hydrogen to react with the sulfur, producing hydrogen sulfide, which can then be readily removed from the oil. Numerous solvent extraction methods are being tried and tested under ERDA and industry sponsorship. Pilot plants are currently operating in a half dozen locations in the United States.

Pyrolysis extracts the volatile material in coal by heating it to high temperatures in successive stages. This volatile material contains medium-Btu gas and thick synthetic crude oil. Hydrogen is added to the mixture to remove the contaminants, which makes this oil suitable as refinery feedstock. The synthesized medium-Btu gas can be used either to produce hydrogen for the process, or can be sold for fuel. Char residue from pyrolysis can be used as fuel if the sulfur content is low enough. Pyrolysis liquefaction methods under ERDA and industry funding are in the pilot-plant phase in a number of projects.

Liquid hydrocarbon synthesis uses coal-derived gas that contains high concentrations of carbon monoxide and hydrogen. The carbon monoxide and hydrogen are combined catalytically to produce a liquid hydrocarbon (synthetic oil). By changing the catalyst, and the temperature and pressure of the carbon monoxide and hydrogen combination, methanol is produced instead of a liquid hydrocarbon. The largest coal liquefaction plant in production today is operated by the South African Gas and Oil Company (SASOL). This plant produces about 4,000 barrels of synthetic gasoline per day.

Rationale

It is EPA's responsibility to monitor pollution from synthetic fuel processes and to quantify this pollution in terms of its health and ecological hazard. EPA is also responsible for devising and aiding in the development of controls to eliminate adverse environmental effects of synthetic fuel



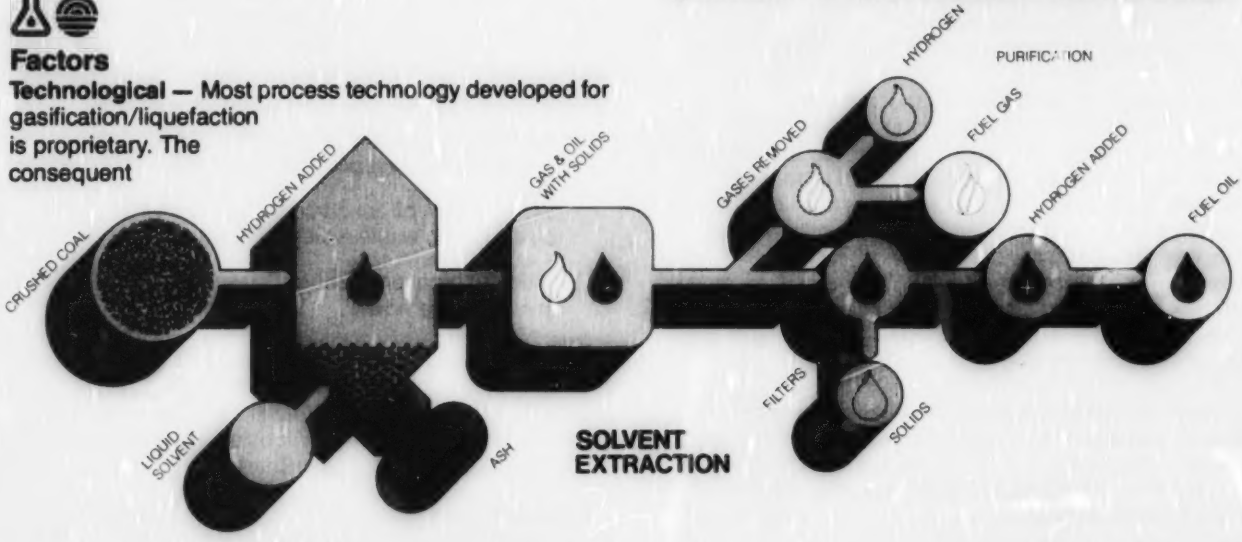
processing.
The data developed on the types and quantities of pollutants and the levels at which they become toxic are used to develop criteria for controlling such pollution.

A synthetic fuel industry will grow rapidly when production processes are proven technically and economically viable. Environmental control technologies developed concurrent with the processes themselves will avoid costly delays which would be necessitated by attempts to add environmental controls after processes are perfected. Environmental controls integrated into processing systems are also likely to be more efficient than add-on methods.

Factors

Technological — Most process technology developed for gasification/liquefaction is proprietary. The consequent lack of information on individual devices hinders their environmental control evaluation. Moreover, the United States has only a few advanced processing pilot plants on which to test control technologies. Some information is being collected on gasification processes in foreign countries. However, the results obtained from monitoring the operation of foreign plants may not be applicable to U.S. plants because of the differences in foreign and U.S. coal and the consequent variations in effluents.

Other technical problems involve the removal of individual pollutants, such as solid waste in the form of particulates, at the high temperatures and high pressures in some of the gasification processes. Large particulates, over a few microns in size, can cause erosion of power plant turbine blades, while the smaller particulates are environmentally undesirable. It is not clear at what stage in the fuel conversion stream these particulates can be most effectively and economically removed. Their effective removal, in any event, will be a benefit both to process technology and to environmental control technology. The current alternatives for removal are during or after gasification. The tradeoffs between these alternatives



cannot be determined today because high-temperature/high-pressure particulate control technology is still in the conceptual and experimental phases.

A further question is whether high temperature/high pressure (HTP) particulate removal mechanisms under consideration will be more effective on some gasifiers than on others. Removal techniques will have to be compatible with a full range of gasification technologies.

An additional concern is the adaptability of electrostatic precipitation techniques to the removal of fine particulates produced in converting low-sulfur and cleaned coal to synthetic fuels. Standard design electrostatic precipitators are inefficient in collecting fine particulates.

Environmental — The types of pollutants resulting from coal gasification/liquefaction are different than those produced in direct combustion. For example, direct combustion yields solid wastes of ash and sludge from stack scrubbers. Coal gasification/liquefaction, on the other hand, produces solid char and tars, gaseous hydrogen sulfide, and spent chemicals. All of these pollutants are potentially detrimental to air and water quality and to land use.

At present, there is no firm estimate of the extent to which these contaminants are produced by individual gasification and liquefaction processes. Nor is the magnitude of the contamination from a full-scale synthetic fuels industry yet predictable.

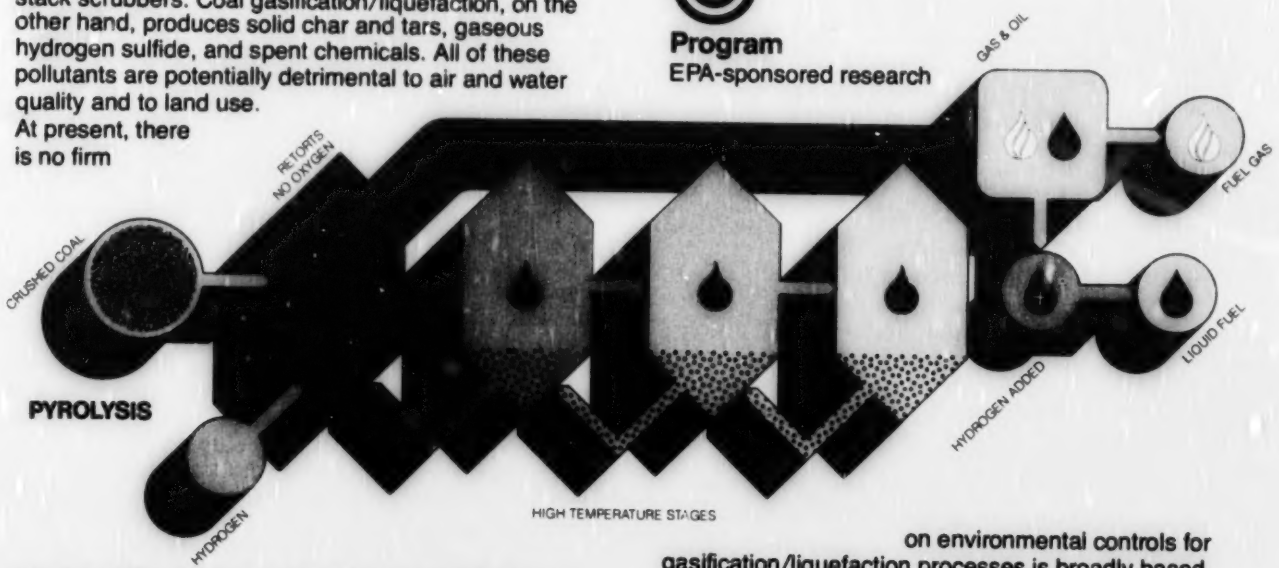
While pollutants in solid form are more effectively controlled than in liquid and gaseous form, care must be taken to ensure that these solid pollutants do not return to air or water through exposure or leaching. Thus, potentially harmful environmental effects from coal gasification and liquefaction may result from contaminants emitted during the preparation of coal for processing as well as from effluents and aerosols emitted from the conversion reactors. Also, by-products of the conversion process itself may cause pollution in the form of liquid and solid wastes.

At present, the exact extent of the health and ecological effects of these potential pollutants remains essentially unknown, although some information is available. For example, minute particulates that are emitted to the air are a known health hazard. Emitted as aerosols, these particulates can remain airborne for long periods of time. They are easily inhaled to accumulate in the lung, and they act as carriers of gaseous pollutants. They also cause restricted visibility. Consequently, a control technology has to be developed to remove most of these fine particulates to eliminate their potential health hazard.

Economic — Pollution control technologies are expensive to develop. Pilot-plant facilities, even bench-scale units, for design and performance tests are very costly. Control devices must be scaled in size to be economically compatible with units designed for gasification/liquefaction.

From the standpoint of industry economics, pollution control technology will require significant capital expenditure. It also may somewhat reduce the efficiency of basic conversion processes, which could adversely affect operating costs.

Program
EPA-sponsored research on environmental controls for gasification/liquefaction processes is broadly based. Study areas include the review of available control techniques, analysis of the engineering and cost aspects of alternative control techniques, and development of new or improved controls for fuel processes under development and in the planning stage. Current projects in these areas involve:



- Sampling and analysis of solid and liquid waste from a coal gasification plant in Yugoslavia.
- Construction of bench-scale facilities to study gas cleanup and waste water treatment.
- Study of high temperature/high pressure (HTP) particulate removal.

Yugoslav Project — EPA has a cooperative project with the Yugoslavian government to study effluents pollutants in air and waste streams from the Kosovo coal gasification plant in Pristina, Yugoslavia. Initial planning for sampling and analysis is underway.

The Kosovo plant uses a fixed bed gasification method, known as the Lurgi process, to produce low-Btu gas from lignite. Operating at capacity with six reactors, the plant

will produce 90,000 cubic meters per hour (cu M/H) of raw generated gas and 60,000 cu M/H of clean gas. It also produces appreciable amounts of tar; heavy, medium-heavy, and light oil; raw phenol; and ammonia water. The Kosovo plant is equipped with only minimal environmental controls. It does not have a sulfur recovery unit or an operational waste water treatment facility.

The Lurgi process is to be used in three industry-sponsored commercial U.S. coal gasification plants. The three are sponsored by the Western Gasification Company (WESCO), the El Paso Natural Gas Company, and the Michigan-Wisconsin Pipeline Company. The results of research at the Kosovo plant will provide a basis for establishing environmental control technologies to be incorporated into the design of U.S. plants, an economically and operationally superior alternative to retrofit controls. Recommendations for municipal regulations on disposal of solid waste from coal gasification plants also will be made on the basis of the study.

The Kosovo project was approved by the U.S. and Yugoslavian governments in June 1976. EPA has allocated $290,000 for the three-year program. Yugoslavia is providing matching funding.

Gas and water treatment — A gas treatment test facility is being constructed at North Carolina State University to treat raw gas that contains large amounts of acids. The facility is being designed and installed by the Aerotherm Division of Acurex Corporation, Mountain View, California. Research on treating waste water is being performed by the University of North Carolina under a grant from EPA.

High temperature/high pressure particulate removal — To develop the technology necessary to remove solid waste particles from fluidized bed reactors used in gasification, HTP particulate removal programs, mainly at the bench-scale level, have been funded. Additionally, some demonstration tests of electrostatic precipitators have also received agency support. An HTP electrostatic precipitator (1700°F) is being developed by Research-Cottrell, Inc., Bound Brook, New Jersey, under a $130,000 contract from EPA. Standard electrostatic precipitators operate at 600° to 800°F.

Filter concepts for HTP control are under study by several contractors. A contract for assessment of granular bed filtering is currently being negotiated. Westinghouse is evaluating the use of ceramics and other materials as filters. Aerotherm is comparing the collection performance of metallic, ceramic, and fabric filters against the performance of electrostatic precipitators.

Air Pollution Technology Corporation, San Diego, has a contract to develop a bench-scale dry scrubber for HTP particulate removal.

Economically viable techniques to remove large and small particulate matter at gasifier exit temperatures are being sought. The cost tradeoffs between high-temperature and low-temperature particulate removal are also being studied.

Pollutant sampling and emission standards — Additional research on identifying pollutants from synthetic fuels processing is expected to begin by early 1977.

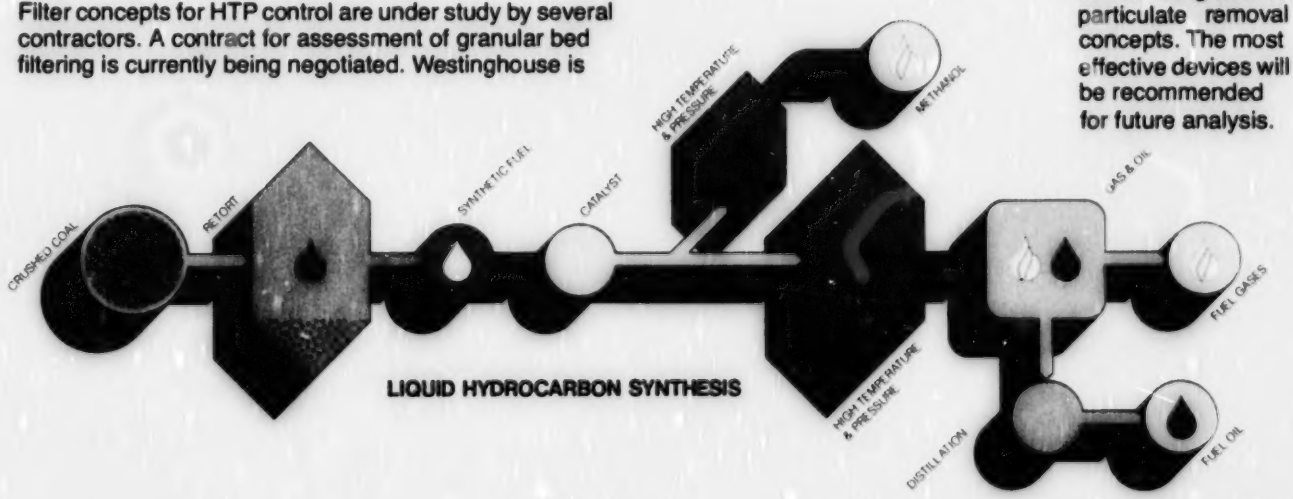
EPA is reviewing preliminary new source performance standards for atmospheric emission of sulfur and hydrocarbons from coal gasification plants. These standards will be published in 1977. But no new standards on water pollution are planned because the demands of environmental control technologies on plant water use are not yet known.

Agency Interaction

EPA, under the auspices of the Interagency Program, is working closely with ERDA to collect data on environmental effects of coal gasification/liquefaction in a number of projects.

EPA is evaluating data on process effluents from ERDA gasification and liquefaction pilot plants — HYGAS in Chicago, Solvent Refined Coal (SRC) in Tacoma, Washington. Joint agency environmental testing is planned. SRC is the liquefaction process that is closest to commercialization. In addition, EPA has entered into an agreement with ERDA to characterize effluents and to provide guidance for ERDA's comprehensive industrial gasification program including the startup and operation of pilot plant gasifiers at Morgantown, West Virginia, and Grand Forks, North Dakota.

EPA and ERDA are coordinating work on particulate removal concepts. The most effective devices will be recommended for future analysis.



LIQUID HYDROCARBON SYNTHESIS

EPA also has a cooperative project with the Occupational Safety and Health Administration and the National Institute for Occupational Safety and Health to sample and analyze effluents from pilot-plant operations.

Outlook

Synthetic fuels may well become a major source of energy in the United States by 1990. Whether the industry that develops to produce these synthetic fuels will use processes that pose the least detriment to the environment will depend on environmental control technology research performed today, as production processes are being developed. Broadly-based, cooperative research programs carried out between agencies of the federal government and industry are necessary if adequate controls are to be developed. This will involve additional pilot-plant facilities to test environmental control techniques for practicality and economic compatibility with advanced fuel processing methods. It will also mean concentrated efforts to collect accurate information on the pollution hazards posed by coal gasification and liquefaction processes. In a rare opportunity, the United States has the option of creating an industry in which pollution control is an integral part of the production processes themselves. Successful integration of processes and environmental control technologies can ultimately result in a synthetic fuel industry that is both efficient in energy production and environmentally sound.

Synthetic Fuels Facts

Process: Coal reacted with hydrogen and oxygen by the application of heat and pressure in the presence of catalysts or chemical solvents can produce a volatile gas or synthetic crude oil. The synthetic gas and oil can be used either directly for combustion or as a refinery feedstock.

Purpose: Monitor synthetic fuel processes to develop and apply environmental control technologies as a synthetic fuel industry evolves.

Problems: Lack of quantitative data.
Solid waste and particulate control.
New and exotic process by-products.
Unknown health and ecological effects of process by-products.
High developmental costs of control.
Uncertain future of synthetic fuels industry.

Potential: Synthetic fuels may become a major source of U.S. energy. Control technologies developed at the same time as synthetic fuel production technology can insure an environmentally sound industry. Environmental controls integrated as part of a plant design increase control efficiency and decrease installation and operating costs.

CHEMICALLY ACTIVE FLUID BED

Process

The chemically active fluid bed (CAFB) process is designed to convert heavy, high-sulfur residual oil to clean, low-sulfur gas. The process also may be applicable to making clean gas from high-sulfur coal.

In applying the process to residual oil, the oil is first heated and then fed to a reactor that contains a fluidized bed of fine particles of limestone. The oil is vaporized in the reactor through a series of catalytic cracking and oxidation reactions. Hydrogen sulfide and some organic sulfur are released from the vaporized oil to be absorbed by the lime in the "boiling" limestone. The remaining hot, low-sulfur fuel gas produced in the process can be piped directly to steam boilers or gas turbines for combustion.

The CAFB reactor contains two sections, one for gasification of the oil and one for regeneration of the sulfur-absorbing lime. In the regeneration step, air reacts with the limestone, freeing it from the sulfur, which is released into the air stream as sulfur dioxide. The sulfur dioxide is removed from the regeneration gas and may be converted to a nonpolluting solid. The cleansed limestone is then recycled through the reactor continuously until it loses its efficiency as an absorbent.

Rationale

Many utilities are required to burn only low-sulfur fuel in order to meet federal and state emissions regulations. This means that large supplies of heavy residual oils remain untapped as sources of fuel for power plants. In the face of the growing shortage of domestic oil supplies, it is important that maximum use be made of all grades of petroleum. By efficiently converting high-sulfur residual oil to clean gaseous fuel, the CAFB process offers an environmentally sound means of freeing this resource for the production of energy.

The process has particular importance as a retrofit mechanism for the numerous gas-fired power plant boilers in the southwest. These boilers cannot be readily converted to the use of high-sulfur heavy oil or coal. Most of the existing gas-fired boilers in Texas, for instance, have a remaining life of 20 to 30 years, but the sources of natural gas to fuel them are expected to be unavailable in just a few years. These boilers are in power plants that currently produce approximately 120,000 megawatts of power. Use of the CAFB process could permit this level of energy production to be maintained throughout the useful life of these boilers.

In addition, the CAFB process offers a technological advantage over other methods of contaminant removal by avoiding the necessity of cooling and scrubbing the gas. These methods lower the heating value of the product gas and the efficiency of the gasification process.

Factors

Technological — Individual power plants may present engineering problems in retrofitting the CAFB process. The age and condition of boilers and the size of burners will have to be considered in designing retrofit equipment. The adequacy of existing pipelines to handle liquid fuels will be another design consideration. But these problems are expected to be readily solved on a case-by-case basis using good engineering practice.

Environmental — The release of large amounts of sulfur in the gasification step of the CAFB process is a basic environmental concern. The efficiency of the fluidized bed of limestone will determine how much of this sulfur, in the form of highly toxic hydrogen sulfide gas, reaches the atmosphere. Efficient removal of the sulfur dioxide gas released from the limestone in the regeneration step is also necessary to maintain air quality.

Another environmental concern is the release of contaminant metals such as vanadium, nickel, sodium, and some alkali metals during gasification. These metals pose a health hazard because of their high toxicity. There is concern that these toxic metallic substances, which may have been present only in trace amounts in the original fuel, will be concentrated as a result of the fuel conversion process in amounts that intensify their pollution potential.

Some of these metals are captured by the limestone in the CAFB, which reduces the chance of toxic air emissions. However, adequate means to remove these metals from the spent limestone will have to be developed to prevent possible leaching of waste stores and the contamination of water supplies in the vicinity of disposal sites. This should not be an insurmountable problem -- it is easier and more economical to control solid residue than liquid or gaseous waste, and the ultimate fate of the contaminant is thus also easier to control.

Economic — Cost estimates for the CAFB process indicate that it may be competitive with post-combustion flue gas desulfurization. However, these estimates are based on assumptions and have not been confirmed operationally. Cost comparisons will have to be made between the CAFB process and the alternative control technologies of demetallization, hydrogasification, partial oxidation with low-temperature sulfur removal, and flue gas cleaning. A major factor will be the cost of retrofitting CAFB to existing boilers.

Program

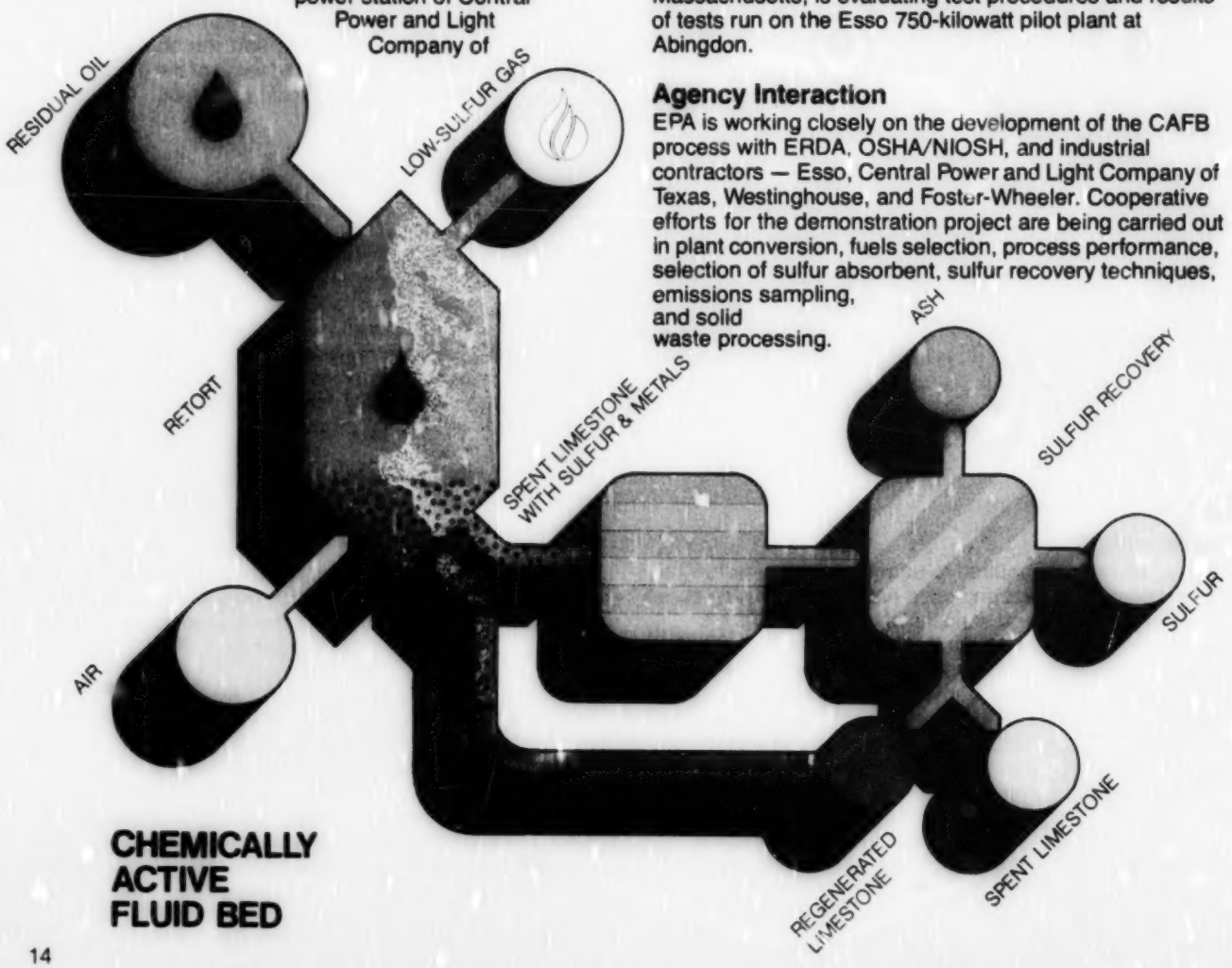
The CAFB process is being retrofitted to the La Palma power station of Central Power and Light Company of Corpus Christi, Texas. The pilot plant, located at San Benito, Texas, will be used to demonstrate the efficiency of the process and to measure emissions. EPA is funding this work through a cooperative project with Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, and Foster-Wheeler Energy Corporation of New York. Modification of the power plant, which is nearly completed, is being carried out by Westinghouse. The plant is being fitted with a boiler of standard design with the incorporation of a CAFB. Resox, a proprietary sulfur removal system developed by Foster-Wheeler, will be tested as part of the process demonstration. Operation of the nominal 20-megawatt plant is expected to begin in September 1977.

Performance tests of the La Palma station pilot plant will be those normally used to proof test a new utility boiler. Emissions tests will be conducted to gauge the ability of the process to meet environmental requirements.

The CAFB process was first developed in 1966 by Esso Petroleum Company, Ltd., at their Research Center in Abingdon, England. By 1970, bench-scale tests of the process confirmed its potential as an effective contaminant-removing fuel conversion technique. Work on the process in both the United Kingdom and the United States has continued under joint funding by both EPA and Esso. The Technology Division of GCA, Bedford, Massachusetts, is evaluating test procedures and results of tests run on the Esso 750-kilowatt pilot plant at Abingdon.

Agency Interaction

EPA is working closely on the development of the CAFB process with ERDA, OSHA/NIOSH, and industrial contractors — Esso, Central Power and Light Company of Texas, Westinghouse, and Foster-Wheeler. Cooperative efforts for the demonstration project are being carried out in plant conversion, fuels selection, process performance, selection of sulfur absorbent, sulfur recovery techniques, emissions sampling, and solid waste processing.



Approximately $1.3 million is allocated for studies of the process in FY77.

Outlook

Preliminary calculations indicate that the CAFB process can be as much as three times more efficient in pollutant removal than initial estimates suggested. However, demonstration tests under a range of operating conditions and grades of fuel are necessary to confirm these indications. The full capability of the process also has yet to be determined. To confidently predict the efficiency of the process over years of operation, it will be important to determine early in the demonstration tests how effectively contaminants are removed.

With the capabilities of the process determined, standards of practice and recommendations for control technologies can be formulated to meet environmental requirements. For these purposes, long-term monitoring of emissions and waste streams will be necessary.

The economics of the process in terms of retrofit, operation, maintenance, and costs added to the fuel product will have to be determined. How well the process competes with the cost of alternative technologies such as flue gas desulfurization also will require analysis.

Work on the CAFB concept to date suggests that it has significant potential as a means of producing clean fuel. The next step in the development of the process is the demonstration at La Palma Station to determine the technical, environmental, and economic realities of plant operation.

Chemically Active Fluid Bed Facts

Process: Heating high-sulfur coal or residual oil in the presence of a fluidized bed of limestone to convert the coal or oil to gas and transfer sulfur and other contaminants to the limestone.

Purpose: Make high-sulfur oil and coal available as a boiler fuel.

Problems: Retrofit of boilers to use the CAFB process.
Transport of liquid fuels to the boilers.
Hydrogen sulfide and sulfur dioxide emissions.
Heavy metals release from spent limestone.
Inadequate information on installation and operating costs.

Potential: CAFB may be more efficient than expected. Fuels produced by CAFB will be clean and air pollution will be reduced. Techniques to handle CAFB solid wastes already exist.

OIL SHALE

Process

The United States has an estimated 2,200 billion barrels of oil locked in dark grey sedimentary rock deposits commonly known as "western oil shale." Most of these deposits lie in the Green River Formation of Colorado, Utah, and Wyoming. The key constituent of this shale from an energy standpoint is kerogen, a solid oily hydrocarbon that can be extracted and processed to produce oil.

At present, there is no commercial production of oil shale in the United States. However, awareness of the dwindling U.S. reserves of conventional crude oil has prompted a gradual increase in the research on processes to produce oil from kerogenous shale. Responsibility for development of these processes rests mainly with ERDA. EPA is monitoring process development to determine the harmful environmental effects of extraction and retorting techniques, and to devise methods of reducing these impacts.

There are two basic approaches to recovery of liquid products from oil shale. One is to mine the shale by conventional methods followed by aboveground retorting of the crushed shale.

Aboveground retorting can be carried out by three methods:

Solids recycling
Internal combustion
External combustion.

These retorting methods differ in how heat is applied to the shale to release the oil.

In solids recycling, heat is transferred to the shale by recirculating heated solid particles — ceramic balls (the TOSCO II process), sand, or spent shale from which the oil has been removed. In the internal combustion process, heat is transferred directly to the shale by maintaining a combustion zone in the retort. In external combustion, a gas is heated by combustion external to the retort. The hot gas is then circulated through the retort containing the shale. In each method, the heat applied frees the oil from the shale.

The other method of recovering oil from shale is its extraction by retorting the shale directly within the rock formation using in-situ techniques.

In in-situ retorting, a cavern is first created by conventional mining. Following this step, the overlying shale is blasted with explosives, which fills the cavern with rubblized shale. The rubblized shale is then retorted in the cavern by combustion that progresses slowly through the rubblized shale. This heating process produces raw shale oil. This liquid petroleum product is then pumped from a sump at the bottom of the cavern.

Most environmental research to date has focused on aboveground recovery and retorting because the technology is more highly developed than in-situ techniques. However, future emphasis on in-situ recovery can be expected because initial cost estimates indicate that in-situ methods will be cheaper than aboveground recovery. In-situ retorting is also potentially less disruptive to the environment because the spent shale remains in place.

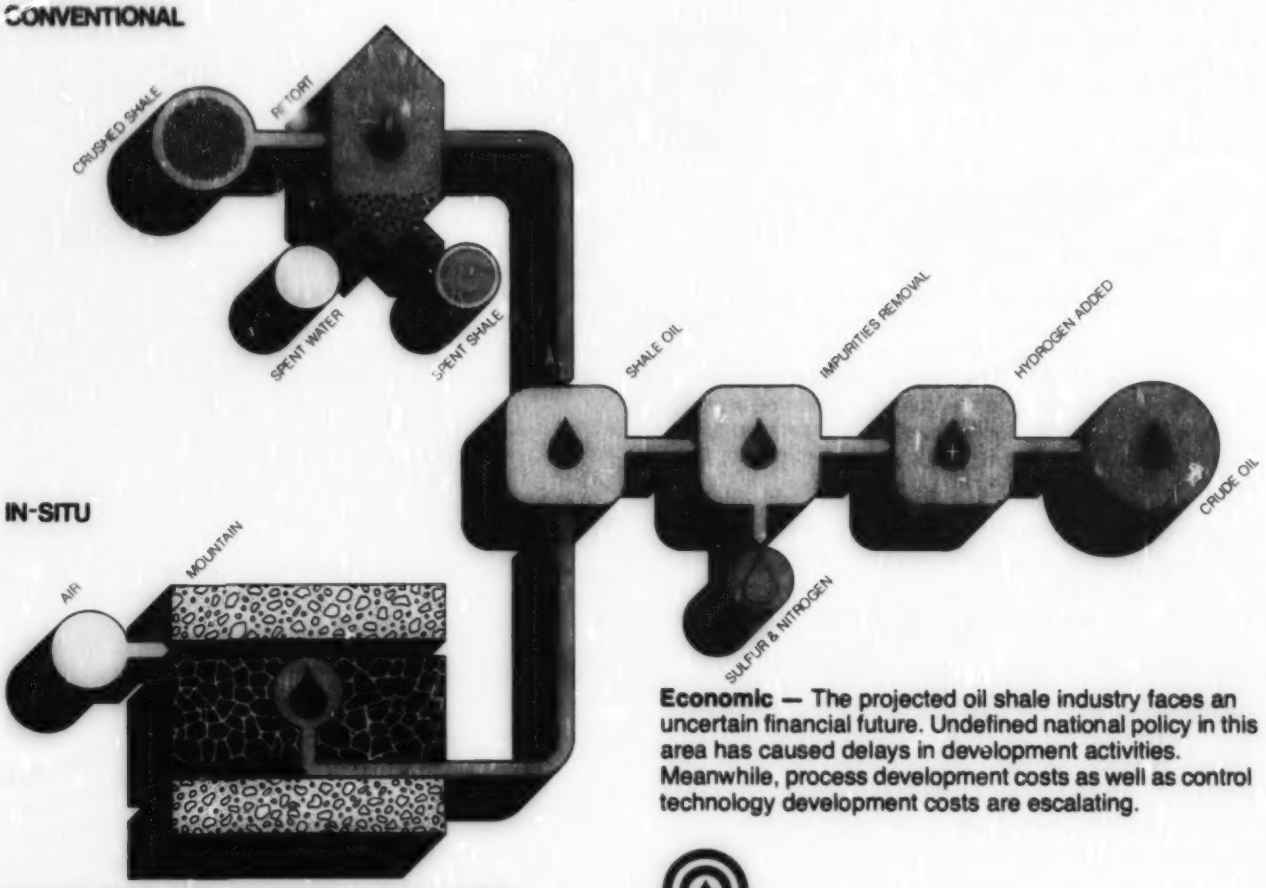
EPA objectives in control technology research for oil shale processing are the broad assessment of processing effects on the environment, the characterization of process stream discharges, and the determination of control technology requirements.

Rationale

The U.S. oil shale resource is extremely large. It is second only to coal in estimated reserves. The availability of large quantities of crude shale oil for refinery products such as gasoline and diesel and jet fuels could sharply expand the U.S. energy supply. The recovery of shale oil, of course, depends on the development of a viable extraction and retorting industry. EPA research on pollution control technologies for oil shale is aimed at determining the environmental effects of the extraction/recovery processes as they are being developed. This will allow time for careful evaluation of impacts and development of suitable controls.

Factors

Technological — The new, developing technology of in-situ oil shale processing poses a challenge in finding ways to make environmental measurements on which to base pollution control technologies. Few opportunities exist for direct measurements of potential pollutants



because there is little equipment — vents, stacks, pipelines — involved in the process.

Environmental — Major sources of environmental impacts will be the mining operations and the large quantities of dust from these activities, the pollutant emissions to the atmosphere from the retorting processes, the large amounts of spent shale produced in the retorting step, and the rapid influx of population to the mining/processing sites, which may create adverse social and economic conditions.

Oil shale processing and the revegetation of spent shale piles will consume large amounts of water. There is concern over the effect of this added demand on the existing demand for water in the semi-arid region of the Colorado River Basin where an oil shale industry would be located.

Large amounts of soluble salts will be contained in the piles of spent shale. There is concern over the leaching of this spent shale, which could increase the salinity of streams and groundwater. Potentially toxic runoff from spent shale could also pose an environmental problem.

The United States has had experience only in oil shale pilot-plant operations. This limits the data available on which to base environmental studies. Some information is available through the Soviet Union on the Estonian oil shale industry, which has been in operation for 30 years. However, there is a question whether the information on effluents from this source is fully transferrable to U.S. research because Estonian shale is different than U.S. shale.

Economic — The projected oil shale industry faces an uncertain financial future. Undefined national policy in this area has caused delays in development activities. Meanwhile, process development costs as well as control technology development costs are escalating.

Program

Research on environmental control technology for oil shale mining/processing is concentrated on retorting emissions characterization and control, solid waste handling, revegetation, ambient air quality, ground water pollution, and socioeconomic impacts.

TRW, Inc., and Denver Research Institute (DRI), Denver, Colorado, are performing a broad environmental assessment of the effects of oil shale processing. This research is part of a major overall contract funded by EPA. Preliminary results from this study outline the status of oil shale technology and projected environmental impacts, including the types of emissions and their potential significance. Process monitoring programs are described as well as the environmental implications of shale oil use.

As part of the TRW/DRI program, emissions from direct and indirect retorting were sampled at the Anvil Points pilot plant in Colorado. The work was carried out in cooperation with ERDA and Paraho Development Engineers, Inc., to locate points in the retorting process that could become waste streams. Sampling techniques and analytical methods were also defined.

EPA has contracts with Colorado State University (CSU) for studies of solid waste control. Erosion and percolation control and concentrations of salt, toxics, and carcinogens in spent shale runoff and leachate are under investigation. Plant species for revegetating spent shale tailings are being studied.

In addition, CSU is modeling groundwater hydrology and leaching effects, including pollution of underground aquifers. Stream desalinization is also being studied.

A large-scale regional impact study of energy development, including oil shale, is being funded by EPA at the University of Oklahoma and Radian Corporation, Austin, Texas. Emission estimates will be used in air quality models being developed by EPA.

Socioeconomic effects of oil shale development are under investigation by the Economic Research Service of the U.S. Department of Agriculture, under EPA funding. This study is part of the integrated assessment of western energy source development. Projected land use impacts, overloading of existing facilities, and changes in local lifestyles are being studied to find ways to minimize the adverse effects of boom-town phenomena.

Agency Interaction

Interagency Program funds have been allocated to the U.S. Bureau of Mines for research on mine design and its effect on emissions, to the U.S. Geological Survey for air quality and groundwater studies on federal oil shale leases, and to the states of Colorado and Utah for air quality monitoring at demonstration sites.

EPA, ERDA, and NIOSH have a cooperative program with the Soviet Union to study health effects of the Estonian oil shale industry. Chronic pulmonary disease from exposure to dust and potential carcinogenic effects are receiving primary attention.

Under a cooperative arrangement with ERDA and NIOSH, EPA plans to set up a materials repository for various forms of energy products including oil shale. Data on these materials will be used to project the impacts of shale oil development on human and aquatic life, on vegetation, and on air and water quality.

EPA is developing cooperative agreements with ERDA on in-situ and surface oil shale processing. EPA pass-through funds will be used as part of a joint research project at Anvil Points to determine the quality and quantity of retort water produced, identify gaseous emissions from the retort, dust emissions from work areas, and other environmental effects.

Outlook

The precise nature of an oil shale industry, as it develops, is not yet clear, although a number of processes are in various stages of development. Environmental evaluations of these processes are under way. These evaluations will form the basis for environmental controls that can be integrated into shale oil production processes.

Oil Shale Facts

Process: Retorting of oil shale releases oily hydrocarbons that can be processed to produce oil. Retorting can take place above ground with mined and crushed shale or below ground, in situ, with rubblized shale.

Purpose: Develop adequate environmental control technologies for the oil shale industry as it emerges.

Problems: Lack of quantitative data.
Lack of means to assess environmental impacts.
Competing demands for water in semi-arid western states.
Meeting strict ambient air quality standards.
Large amounts of solid waste for disposal.
Revegetation of mined areas.
Escalating processing costs.
Financial uncertainties of the impact of a national energy policy on an oil shale industry.

Potential: Environmental control technology can be developed in parallel with an emerging oil shale industry. Parallel development can lead to designed-in environmental controls, more efficient control technology operations, and fewer economic impacts than retrofit controls.

LIQUID FUELS CLEANING

Process

Demetallization, desulfurization, and denitrification are chemical processes of removing contaminants from liquid fuel prior to combustion. In these processes, the fuel is combined with hydrogen and passed over a bed of catalyst in a reactor at high temperature and pressure. These hydrotreating processes result in a catalytic reaction that transfers contaminants — heavy metals, sulfur, or nitrogen — to the catalyst. The catalyst is then removed, cleansed of its scavenged impurities, and reused. Chemical elements used as catalysts include cobalt, molybdenum, bauxite, tungsten, and other similar materials. Targets for these catalytic scavenging processes are fuels that contain large amounts of vanadium and nickel (400 to 1000 parts per million or more) and sulfur (3% to 3.5% or more).

Rationale

Research in contaminant removal from liquid fuel before combustion is motivated by both environmental and economic considerations. A variety of hydrodesulfurization and hydrodenitrification technologies using catalytic scavengers are already in use by refineries. These hydrotreating processes are applied to liquid fuels to remove contaminants that poison and shorten the life of the catalyst. Hydrotreatment of fuel feedstock thus increases the lifetime of catalysts and allows refineries to utilize a greater variety of grades of crude oil, particularly high-sulfur crudes. Hydrotreated material can be used as a feedstock for subsequent processing or as a blending stock to produce finished petroleum products containing reduced amounts of sulfur and nitrogen. The process of hydrotreating may also be applicable to producing clean fuels from liquid synthetic fuels or shale oil.

Hydrotreating is an environmentally attractive process because it removes potential pollutants at the same time that it increases the efficiency of the refining process. Moreover, the contaminants are mainly deposited on solids rather than being emitted to the atmosphere. Solid waste is easier to control than are atmospheric emissions. Consequently, solid waste is less threatening to the environment.

The goal of EPA research in catalytic hydrotreating is to find more effective and versatile scavenging materials, particularly those that remove two or more types of contaminant simultaneously. At present, a different catalyst is used for each contaminant in a separate removal step. If one type rather than several types of catalysts could be used to remove contaminants, the amount of solid waste might be reduced. Use of a single catalytic reaction could also reduce the amount of energy required for contaminant removal.

Precombustion removal of contaminants from liquid fuel may become cheaper than present post-combustion techniques as hydrotreating technologies are improved. If this proves to be true, large and small industrial users would benefit economically by being saved the cost of performing post-combustion cleanup.

If improved scavenging processes are developed, they could be an effective complement or alternative to combustion modification techniques (such as the CAFB process) designed to remove contaminants.

Factors

Technological — Development of more advanced methods of hydrotreating to remove contaminants in liquid fuels is hampered mainly by the lack of quantitative information. There is only limited information on methods of disposing and using heavy metals recovered from residual oil. Simultaneous removal of sulfur and nitrogen is logically desirable. However, there are no firm data as yet on the feasibility of the concept. Information on the

sulfur, nitrogen, and metal content of synthetic fuels is just beginning to become available.

In addition, performance information on catalytic scavenging processes developed by industry is difficult to obtain because these processes are proprietary.

Environmental — Information is lacking on how much of the heavy metal, sulfur, and nitrogen content of liquid fuels is removed by fuel processing technologies under development. For example, shale oil is estimated to contain a large percentage of nitrogen, 2%. However, it is not known how much this nitrogen would contribute during combustion to formation of nitrogen oxide, a major component of air pollution. Consequently, it is difficult to determine the level of contaminant removal to be sought in precombustion processes.

Economic — Research on contaminant removal using hydrotreating with improved catalysts is not yet far enough along to determine process costs. However, it is known that a major cost factor will be the supply of hydrogen required.

Program

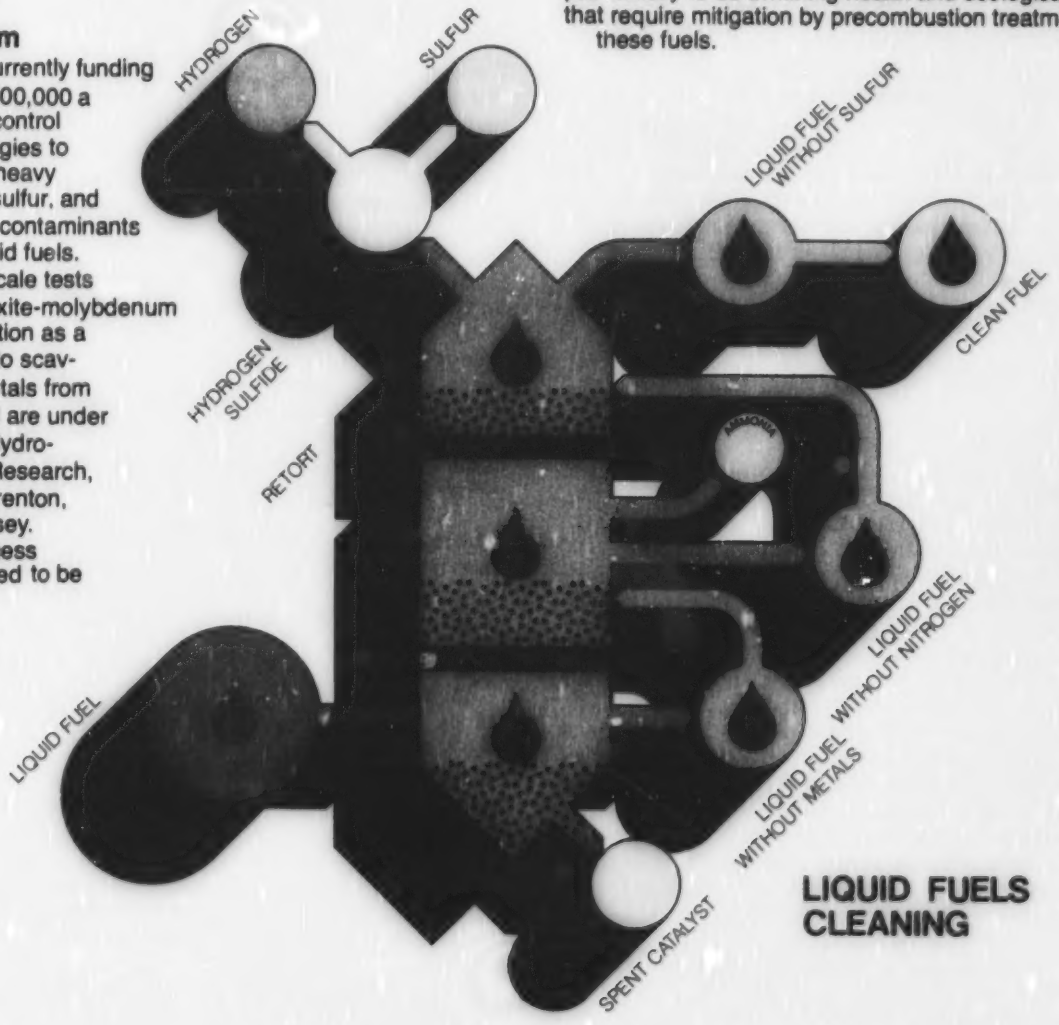
EPA is currently funding about $200,000 a year on control technologies to remove heavy metals, sulfur, and nitrogen contaminants from liquid fuels. Bench-scale tests of a bauxite-molybdenum combination as a catalyst to scavenge metals from heavy oil are under way at Hydrocarbon Research, Inc., in Trenton, New Jersey. The process is intended to be used as a cleansing mechanism before oil undergoes hydrodesulfurization.

Hydrocarbon Research, Inc., is also reviewing the properties of existing catalysts to determine the optimum characteristics for nitrogen removal.

EPA also has a cooperative project with the Soviet Union in the pre-treatment of oils to remove heavy metals. In this project, Soviet catalysts are being tested on heavier grades of U.S. oils and U.S. catalysts are being tested on Soviet oil types to determine the relative efficiencies of metal removal.

Under a grant from EPA, Massachusetts Institute of Technology is performing laboratory work to define the basic kinetic and reaction mechanisms of hydrodesulfurization and hydrodenitrification. The experiments are being carried out on basic compounds of sulfur and nitrogen at atmospheric pressure. The work will be extended to study these mechanisms on more complex sulfur and nitrogen compounds at higher pressures.

Research is also under way to characterize pollutants from processing of heavy liquid fuels and the ways these pollutants are transported in the environment. This work is preliminary to determining health and ecological effects that require mitigation by precombustion treatment of these fuels.



LIQUID FUELS CLEANING

Agency Interaction

Research in scavenging processes for controlling pollutants in liquid fuels is in the early stages. A pilot plant designed as an add-on to an existing conventional hydrodesulfurization system will be necessary to confirm results of bench-scale tests. EPA hopes to interest industry in joint development of pilot-plant facilities and commercialization of scavenging processes that prove to be technically feasible and effective from an environmental viewpoint.

EPA plans to provide Interagency Program funds to OSHA/NIOSH to sample and analyze emissions during pilot-plant tests.

Outlook

The technology of hydrotreating liquid fuels to clean them before combustion has already been developed by oil companies to improve the efficiency of their operations and the quality of their products. Today, more hydrotreating processes are being installed than any other type of refining process. Rapid adoption of these processes is expected to continue as refineries are forced to use heavier, high-sulfur fuels and, at the same time, to meet emission standards. The inherent capability of hydrotreatment processes to accommodate environmental as well as operational requirements is therefore jointly attractive both to industry and to EPA. EPA emphasis is on research to improve environmental effectiveness of hydrotreating as a complement to industry research on process efficiency. Improved catalysts that reduce the number of cycles required for contaminant removal are a major goal of this effort.

Liquid Fuels Cleaning Facts

Process: Mixing hydrogen with liquid fuel before combustion and passing the mixture over a catalyst at high temperature and pressure to remove metals, sulfur, and nitrogen. The contaminants are transferred to the catalyst, which is cleansed and reused.

Purpose: Develop catalysts that remove more than one contaminant at a time.
Develop catalysts that remove greater amounts of contaminants.

Problems: Lack of quantitative information.
Use or disposal of contaminants, especially heavy metals.
Contaminant content of synthetic fuels is unknown.
Unknown process costs.

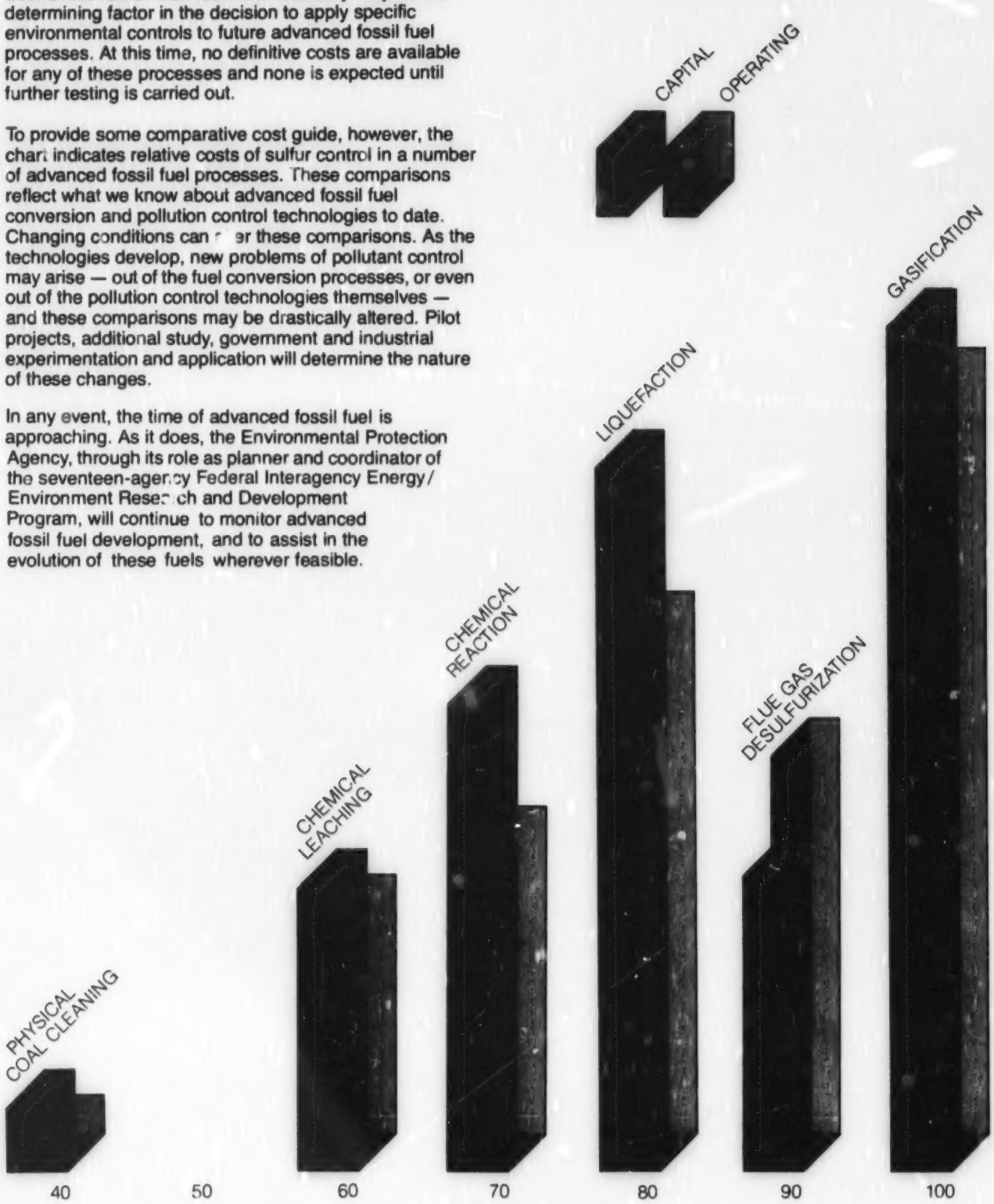
Potential: Hydrotreating removes pollutants and increases refinery efficiency at the same time. Air pollution is transformed to easier-to-handle solid waste. Better catalysts could further reduce pollution from liquid fuel combustion. Precombustion removal of contaminants may become cheaper than present post-combustion techniques. Post-combustion costs and scrubber by-products could be reduced. Hydrotreating may be applicable to synthetic fuels.

PROSPECT

Economics rather than technical feasibility may be the determining factor in the decision to apply specific environmental controls to future advanced fossil fuel processes. At this time, no definitive costs are available for any of these processes and none is expected until further testing is carried out.

To provide some comparative cost guide, however, the chart indicates relative costs of sulfur control in a number of advanced fossil fuel processes. These comparisons reflect what we know about advanced fossil fuel conversion and pollution control technologies to date. Changing conditions can alter these comparisons. As the technologies develop, new problems of pollutant control may arise — out of the fuel conversion processes, or even out of the pollution control technologies themselves — and these comparisons may be drastically altered. Pilot projects, additional study, government and industrial experimentation and application will determine the nature of these changes.

In any event, the time of advanced fossil fuel is approaching. As it does, the Environmental Protection Agency, through its role as planner and coordinator of the seventeen-agency Federal Interagency Energy/Environment Research and Development Program, will continue to monitor advanced fossil fuel development, and to assist in the evolution of these fuels wherever feasible.



FURTHER READING

Synthetic Fuels — Oil Shale, Coal, Oil Sands, *Quarterly Report, Volume 14, Number 1, Cameron Engineers, Inc., Denver, Colorado (March 1977).*

This report contains a number of sections covering a spectrum of issues related to synthetic fuels development using oil shale, coal, and oil sands. Progress in research and development as well as latest regulations is given.

Energy Alternatives: A Comparative Analysis, *The Science and Public Policy Program, University of Oklahoma, Norman, Oklahoma (May 1975).*

A survey of the energy resource systems available in the United States, this report presents detailed but easily understood descriptions of exploration, extraction, transportation, and processing of various fuels. Numerous figures are used to illustrate concepts and tabular information abounds. Environmental effects of the energy resources are described in some detail and an attempt is made to compare costs and efficiencies of different fuels used in energy production. A good overall reference.

Energy Facts II, *The Science Policy Research Division, Congressional Research Service, Library of Congress. Prepared for the Subcommittee on Energy Research, Development, and Demonstration of the Committee on Science and Technology, U.S. House of Representatives (August 1975).*

This is a follow-up report to the very popular *Energy Facts* report published in 1973 by the same committee. *Energy Facts* described the history and status of world energy production, consumption, and supply. *Energy Facts II* updates that data. Virtually no text. Tables, charts and graphs on demand, supply, production, reserves, imports and exports, sales, prices, and so on. A storehouse of concise factual data. A good glossary at the end contains general energy terminology.

Energy From Coal — A State-of-the-Art Review, *ERDA 76-67, prepared for the Office of Fossil Energy, U.S. Energy Research and Development Agency, by Tetra Tech, Inc., Arlington, VA 22209 (1976).*

This report is a relatively nontechnical overview of coal as an energy source. The text serves as an introduction to coal — treating supply and demand, mining and transportation, and advanced conversion processes for gasification and liquefaction. Only passing references to coal's environmental impacts. Flow diagrams and some schematics illustrate most of the coal conversion processes being investigated by ERDA. Two appendices describe major gasification and liquefaction programs under way.

Interagency Energy/Environment Research and Development Program — Status Report III, *EPA-600/77-032 prepared by Office of Energy, Minerals and Industry, Office of Research and Development/ Environmental Protection Agency (April 1977).*

A detailed status report of the Interagency Program including program history, organization, and some of the basic reasons for the program. Some program cost figures are given for environmental control technology and for health and environmental effects studies of energy use. This report shows the status of research on the health and ecological effects due to energy usage.

Proceedings of: National Conference on Health, Environmental Effects, and Control Technology of Energy Use, *EPA 600/7-76-002 prepared by Office of Energy, Minerals and Industry, Office of Research and Development/Environmental Protection Agency (May 1976).*

Over 60 papers, most of a relatively specialized nature, on diverse subjects ranging from atmospheric transport of energy-related pollutants and monitoring problems to broadly based assessments of integrated energy systems. Some papers are easily read and require no particular technical specialty while others are only for experts in a very particular field. At the end of each chapter are questions raised from the floor of the conference and responses by a panel of specialists. These questions and answers are filled with facts and often the reader can get a real insight into the enormity of the problems within the energy-environment dilemma.

EPA Program Conference Report — Fuel Cleaning Program: Coal, *EPA-600/7-76-024, Interagency Energy-Environment Research and Development Program Report, Office of Energy, Minerals and Industry, Office of Research and Development, Environmental Protection Agency (October 1976).*

Ten papers on coal cleaning and control technologies for environmental effects; good question and answer section. Text highly technical but clearly written.